High Frequency Acoustic Channel Characterization for Propagation and Ambient Noise

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LONG-TERM GOALS

The long term goals of this project are to research the physics of high frequency (1-50 kHz) acoustic propagation and ambient noise in the ocean. This work is relevant to many types of Navy sonars such as active ASW and MCM systems and underwater acoustic modems for communications. Improved understanding is leading to better ways to adapt to and exploit the environment for enhanced sonar system performance.

OBJECTIVES

One of the main objectives of this research is to develop techniques that use ocean ambient noise field to characterize seabed properties. Better knowledge of the seabed will improve the capabilities of sonar performance prediction tools and are the basis for improving sonar performance through environmental adaptation of the systems. Many factors can contribute to variability observed in sonar performance but the seabed type often has the strongest impact on propagation (especially in shallow water) and is one of the quantities that can be measured and archived for future use. In this work, an ambient noise based geoacoustic inversion methodology has been developed and this was applied to a data set that also had transmissions from a towed sound projector. These tow transmissions were used to help validate the quality of the ambient noise inversion results.

APPROACH

Although there are a variety of methods for characterizing the properties of the seabed there are several advantages to using ambient noise: 1) Only receivers are required; this implies no sound projectors or explosive sources are needed and the measurement strategy is simple (i.e., doesn't require receivers in one location and a platform with a source deployed in another). 2) Ambient noise conveniently contains energy over a broad band of frequencies so measurements can be tailored to the frequencies relevant for the application. 3) A completely passive system can generally be placed anywhere without concerns (to the environment, for example). 4) When fielded as an autonomous system it consumes a relatively low amount of power which is desirable for long deployments. 5) There is also potential for rapid, *in-situ* seabed characterizations (i.e., through-the-sensor) which can reduce reliance on archived data.

Two ambient noise techniques have recently been developed and are used here to characterize the seabed. Both of these techniques use a vertical array of hydrophones in either a fixed (moored) or

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14. ABSTRACT
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15. SUBJECT TERMS

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drifting configuration. The first technique used here we refer to as the “R-θ” method and this uses the intensity of vertically beamformed noise to determine an approximation to the magnitude-squared bottom reflection loss (i.e. power reflection loss) [Harrison and Simons]. The second uses the coherent noise field in the vertical direction as a “passive fathometer” to estimate the seabed layering [Siderius, Porter and Harrison]. This process can be thought of as a correlation between the ambient noise in the beam arriving from the surface (straight up) with the beam arriving from the seabed (straight down). The beam coming from the seabed will contain an exact replica of the surface beam delayed by the two way travel time to the seabed. Further, this beam will contain echoes from seabed reflections that occur at different layers. The correlation provides a pulse compression effect that shows impulses at the layer boundaries with time resolution proportional to the bandwidth. The reflection intensity (R-θ) and the passive fathometer returns are observables that can be used to determine a complete geoacoustic description of the seabed using inverse methods.

The geoacoustic inversion approach used here is to first parameterize the seabed into layers based on the passive fathometer returns. Once these layers are determined they are fixed in the geoacoustic model. Next, a random guess is made for the compressional sound speed, density and attenuation for each layer. Using numerical methods we construct simulated observables just like the measured observables using the seabed properties from the random guess. A cost function is defined to quantify the agreement between the measurement and the simulation. A search is performed over all possible combinations of seabed properties to determine the set that produces the best match with the data. A genetic algorithm is used to direct the search and make the process more efficient. The final result is a fairly detailed description of the seabed consisting of several layers each with a geoacoustic description. An important point is that generating the simulated observables is efficient since only a bottom loss calculation is needed along with signal processing to account for beamforming effects; no sound propagation modeling is required.

Although we have a methodology for estimating seabed properties we would like to have confirmation that these properties are, in fact, well estimated. For this analysis, a data set was chosen that not only contains ambient noise but also has a towed sound source recording. The towed source transmissions took place immediately after the ambient noise measurements. The calibration and source to receiver ranges did not allow for a meaningful transmission loss comparison, but the data were well suited to impulse response and matched field comparisons. Matched field beamforming was used to localize the source range and depth and matched field geoacoustic inversion was used to directly compare seabed property estimates with the ambient noise inversion results.

WORK COMPLETED

To illustrate, data was taken from the MAPEX2000 experiment which took place near Sicily, Italy. The array was in a fixed position and had 64 hydrophones (3 nested apertures of 32 hydrophones with 0.5, 1 and 2 m spacing). For this analysis only the 32 hydrophones in the 0.5 m spaced aperture were used. The frequency band considered was up to 1500 Hz. The vertical array was fixed and therefore many minutes of ambient noise data could be averaged and here about 10 minutes were used. In the left panel of Fig. 1, the vertically steered noise intensity is shown with the angles steered toward the surface being at higher intensity than those from the seabed as expected due to bottom losses. In the right panel is the approximation of the power reflection loss inferred from the ambient noise field. Note, this is power reflection loss (the true reflection loss is complex) and the measurements are also somewhat smeared by the beamforming process.

The passive fathometer processing was used to directly measure the seabed layering [Siderius, Porter and Harrison]. In a sense, the passive fathometer returns provide the missing information needed to extract the true reflection loss from a power reflection loss. The seabed layering can cause complicated frequency dependent losses due to constructive and destructive interference that occurs as acoustic waves reflect off various layers in the sub-bottom. One example of this interference can be seen as the band in the right panel in Fig. 1. Failure to account for the layering can result in large errors when modeling the pressure field. Shown in Fig. 2 are the coherent bottom echoes from the MAPEX2000 array (same data as for the reflection loss estimate in the upper right panel except processed coherently). The notable features are the strong returns from the seabed at 130 m (along with one or more thin layers) and also the two layers at about 150 m. The top panel of Fig. 2 shows the envelope of the real valued time series shown in the lower panel.

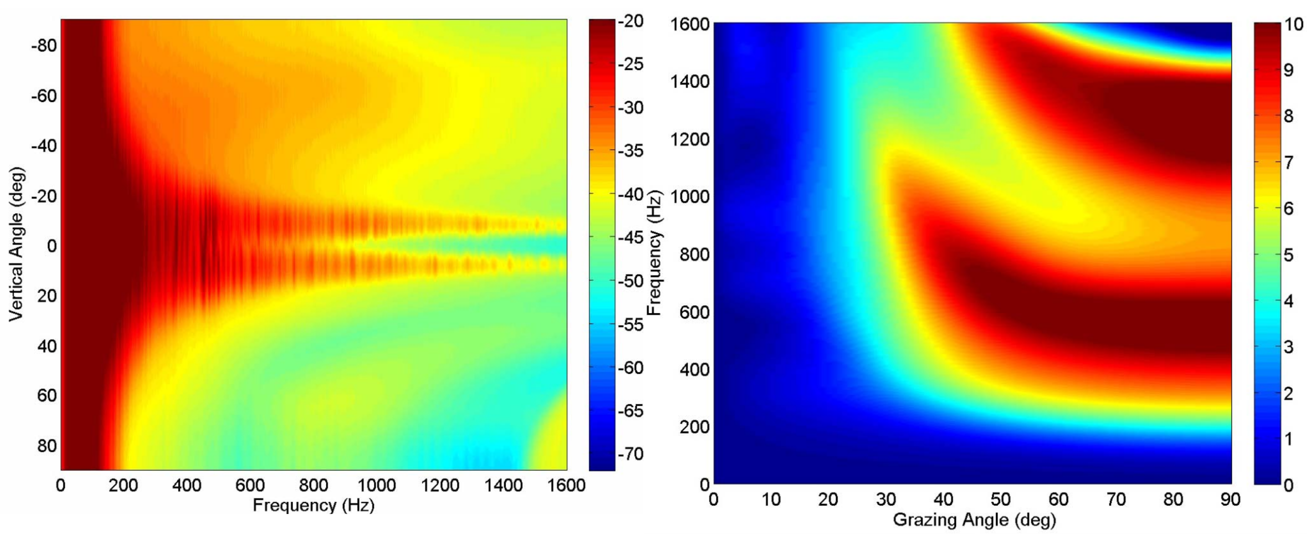

Figure 1: Left panel shows the vertically beamformed ambient noise field. The vertical axis is the beam direction (-90 is up toward the surface, 0 is horizontal and 90 is directly down towards the seabed). The horizontal axis shows the frequency in Hertz. Color scale is in decibels. The right panel shows the approximate power reflection loss in decibels. The vertical axis indicates the frequency and the horizontal axis the grazing angle.

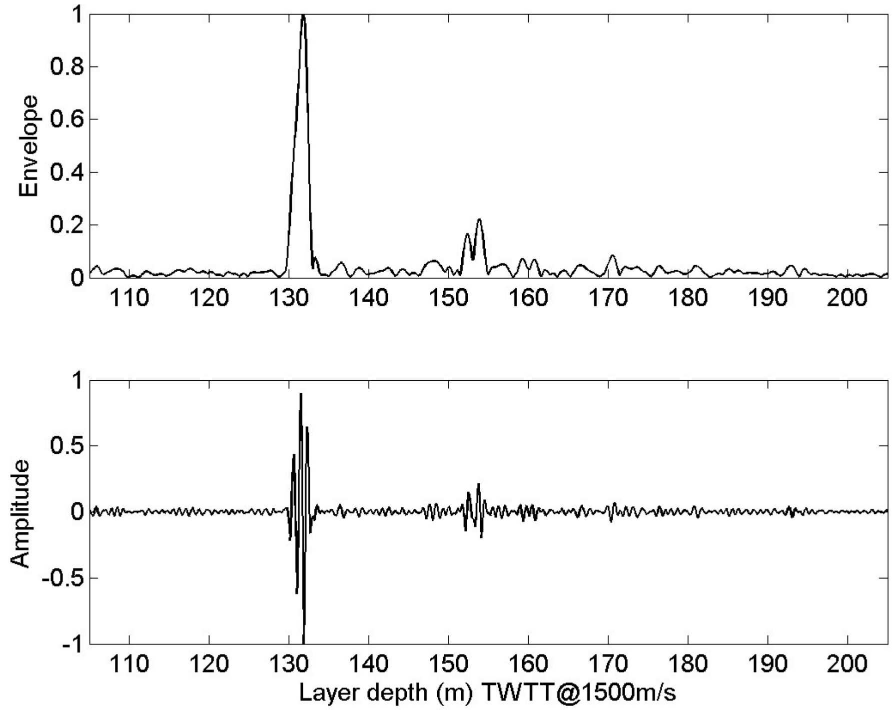

Figure 2: Top panel shows the envelope of the passive fathometer returns taken from ambient noise. The lower panel shows the real valued time-series which better shows the multiple layer structure.

RESULTS

Using the fixed receiver array, the ambient noise field was measured and R-θ and passive fathometer processing was applied to form the estimates for the bottom layering and power reflection loss. The passive fathometer processing was also used to make a slight correction to the position of the array depth relative to the seabed. The previously described geoacoustic inversion processing was applied to the data set. An example of the best fit between simulated and measured data is shown in Fig. 3.

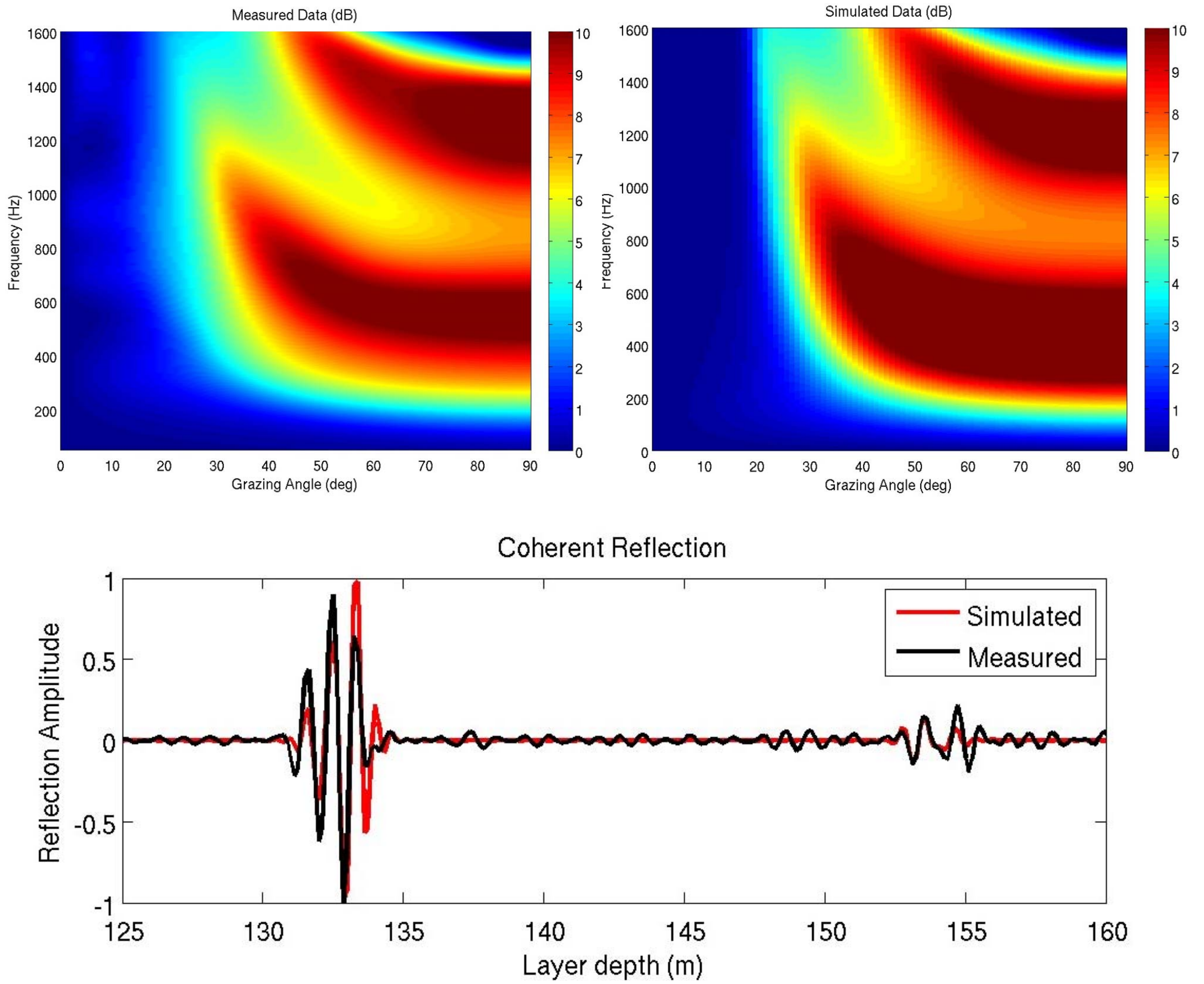

Figure 3: Top left panel shows the power reflection loss from the R-θ processing of measured ambient noise data. The top right figure shows the simulation of the same process using best-fit values for the seabed properties. The bottom figure shows the match between the passive fathometer measurements and the simulation. Both of these processed data types were used to determine the best set of seabed properties.

The seabed properties resulting from the ambient noise inversion are shown in Fig. 4. Note, there are multiple layers representing a fairly complicated bottom structure. The resulting seabed characterization can be used as input to transmission loss models or for environmentally adaptive sonar algorithms. Particularly for matched field processing this methodology might be useful to overcome the usual lack of seabed information needed to generate the matched field replicas.

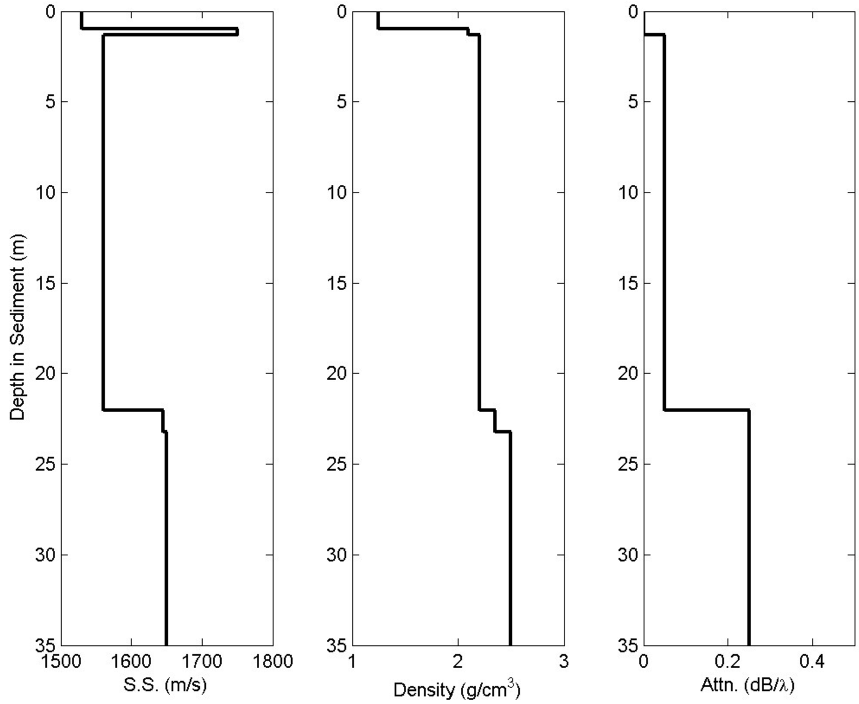

Figure 4: Sediment properties from the inversion of ambient noise data. The vertical axis indicates sediment depth. The left panel shows the sediment sound speed, the middle panel the density and the right panel the attenuation.

One of the validation tests was to use the sediment properties for matched field beamforming. This process is similar to planewave beamforming, but rather than planewaves the more complicated wavefronts are modeled using a propagation code (i.e., a transmission loss model). One of the advantages of using matched field methods is that source recordings on a vertical array can be beamformed to produce an ambiguity surface that shows the likely location of the source in range and depth rather than just an elevation angle. However, the propagation model requires environmental inputs like the seabed properties. The lack of this environmental data is often the cause for matched field methods to fail. With the approach here, the very same vertical array can be used to measure the ambient noise when the source is not present and estimate the seabed properties to create the matched field beamforming replicas. This processing could be done, for instance, when the array is first deployed and the replicas store. When sources are present the matched field beamforming can produce a localization and improve processing gain. Figure 5 shows the range-depth ambiguity surfaces using the seabed properties in Fig. 4 along with a measured water column sound speed profile. Six tonals were used in the beamforming (200, 275, 350, 425, 500 and 575 Hz). The ship range and expected tow depth are shown as the open, white circles in Fig. 5 (the source was actually several hundred meters behind the ship). The matched field beamforming results show the sound source is reasonably well localized in range and depth. (The slight bathymetry changes in the actual environment were neglected here.)

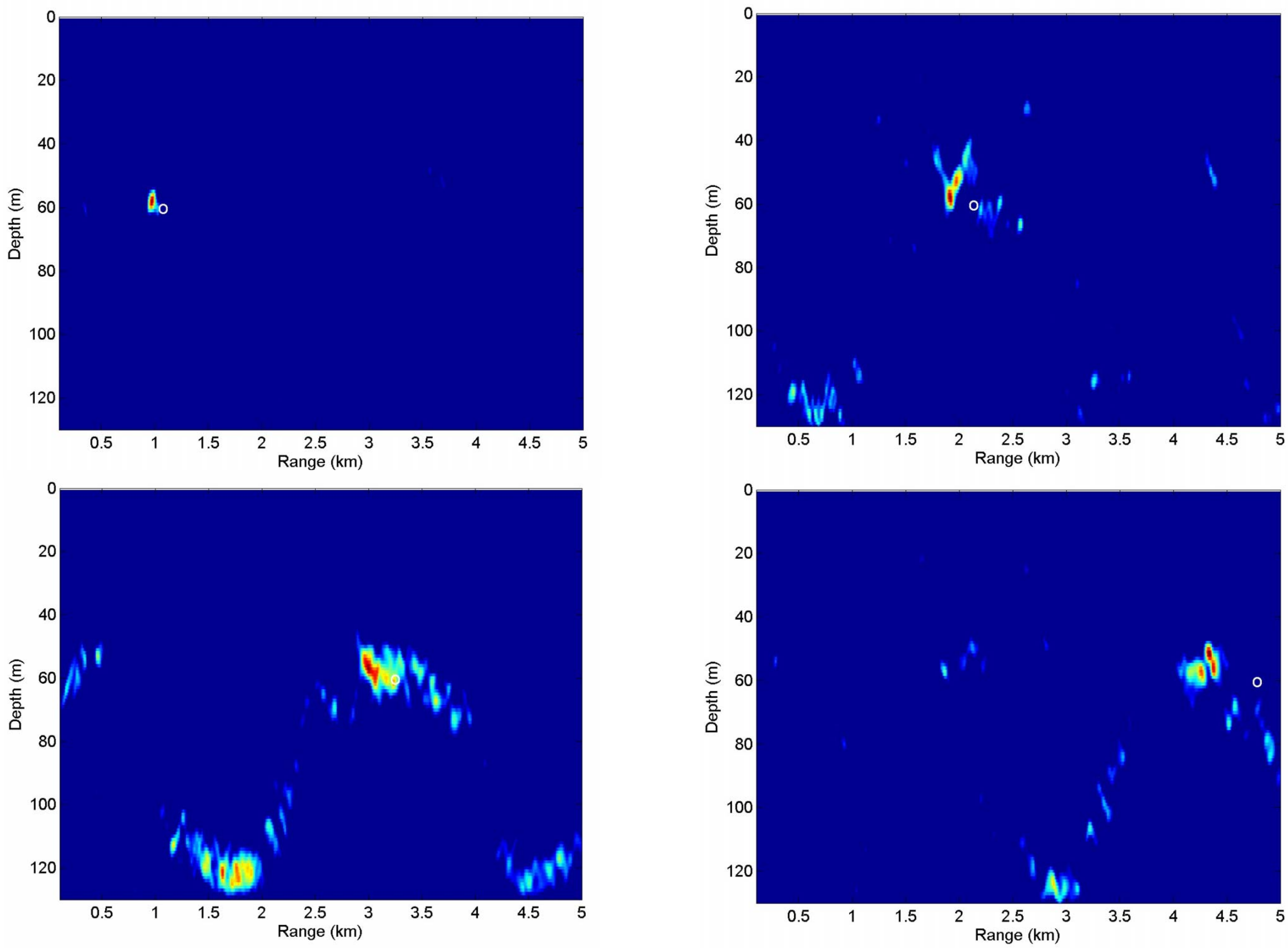

Figure 5: Matched field ambiguity surfaces for a source towed away from the vertical array at four different ranges. The seabed properties shown in Fig. 4 were used along with a measured sound speed profile. The tow ship location is indicated by the white open circle and the source was a few hundred meters behind.

The matched field beamforming results are only a positive indicator and not a complete validation of the correctness of the seabed properties. We also compared the ambient noise inverted seabed properties with a matched field inversion. Matched field geo-acoustic inversion (MFI) is a model based technique that has been applied successfully in characterizing the seabed for the most important parameters for propagation prediction. This is a remote sensing method that uses down-range acoustic measurements to infer properties of the seabed. Computer simulations are used to model the down-range acoustic response to different seabed types, and efficient search algorithms (e.g., genetic algorithms) are applied to find the environment giving an optimal match between modeled and measured data. This may sound similar to the ambient noise approach but with some big differences 1) this requires a sound source with a range separation from the array and 2) the inversion involves propagation modeling 3) the resulting estimates are a type of integrated or effective seabed over the source-array range 4) the sound field interacts with a possibly rough surface that may be difficult to model. The matched field inversion used the sound source transmission at 3.5 km received on the vertical array and a set of tonal transmissions at 200, 275, 350, 425, 500 and 575 Hz. In an attempt to keep the results unbiased the SAGA MFI software was used [Gerstoft]. SAGA is more or less a

turnkey package for data of this type (i.e., tones recorded on a vertical array of hydrophones). The results comparing the two inversions are shown in Fig. 6. The results show reasonable agreement especially near the water-sediment interface. In particular, the seabed sound speed for the two inversion techniques agree well and this is by far the most sensitive parameter. The MFI technique uses a single layer over a halfspace description of the seabed and this is simpler than that from the passive fathometer processing so perfect agreement is not possible. Still, the deep reflector at about 22 m depth is nearly the same for both inversion approaches. Part of the discrepancy between the two inversion approaches for the density and attenuation at the larger depths is likely due to decreased sensitivity of these measurements to those parameters.

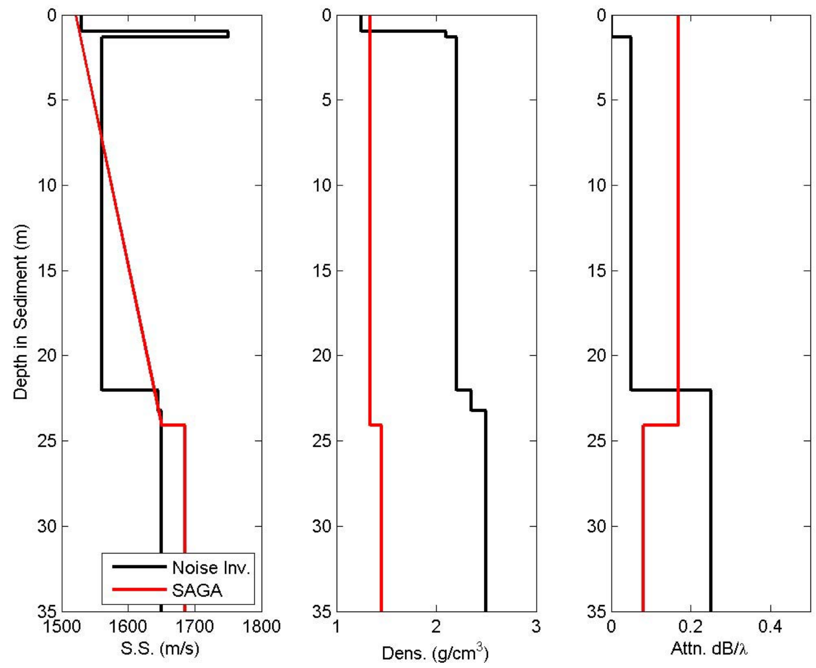

Figure 6: Comparisons between inverting ambient noise data (black line) and using a set of tonal transmissions with matched field inversion approach using SAGA (red). The most sensitive parameter is the sound speed shown in the left panel. The middle panel is the comparison between density estimates and the right panel for attenuation.

IMPACT/APPLICATIONS

This work may have a significant impact on several Navy sonar systems (e.g., ASW, MCM, underwater acoustic communications). Knowing the seabed properties will improve at-sea situational awareness by being able to accurately predict acoustic propagation. And, because this is a passive method it can be designed into a system used for covert activities, low power applications and can be used even in environmentally restricted areas.

TRANSITIONS

Results of this research are being further developed in the Ocean Bottom Characterization Initiative (PMW-120). This involves developing an off-board sensor (over the next several years) that is based on techniques described here and will initially be deployed by the Naval Oceanographic Office.

RELATED PROJECTS

This research has done in close collaboration with Michael Porter and Paul Hursky (HLS Research) with support from the ONR Ocean Acoustics Program and the ONR PLUSNet Project. We have also been collaborating on related projects with Steve Means at the Naval Research Laboratory, Chris Harrison at the NATO Undersea Research Centre, La Spezia Italy and Peter Gerstoft at the Marine Physical Laboratory at the University of California, San Diego.

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